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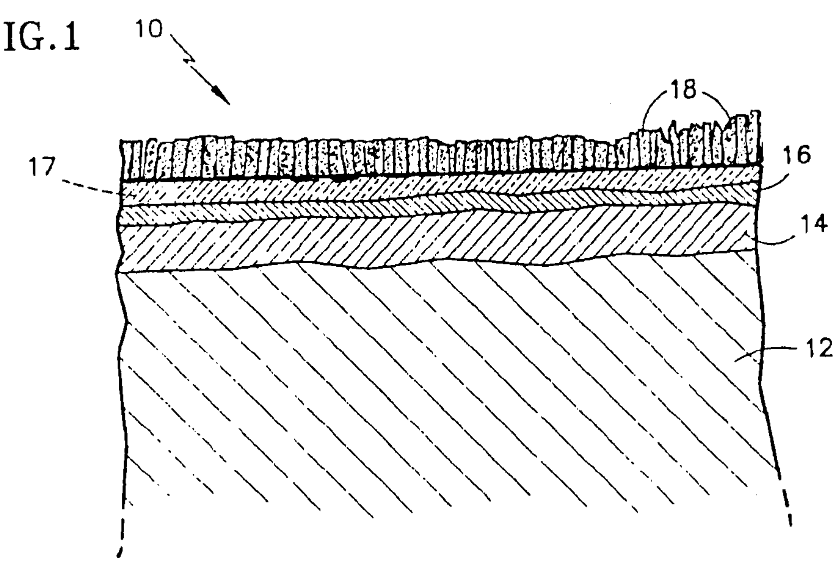
(54) Article having a thermal barrier coating based on a phase-stable solid solution of two ceramics and apparatus and method for making the article

(57) An article (10) having an improved thermal barrier coating (18) is disclosed. The article includes a superalloy substrate (12), and an adherent alumina layer (16) generated on the substrate surface. The article also includes a layer (18) of ceramic material forming a columnar grain, thermal barrier coating on the alumina layer (16). The coating (18) is composed of a generally homogeneous mixture of two materials, such as yttria and ceria and preferably at least about 5w/o yttria, balance ceria. The article (10) may also include an intermediate ceramic bond coat (17), such as a layer of yttria strengthened zirconia, to enhance the adherence of the thermal barrier coating. An associated apparatus and method for making the article are also disclosed.

The TBC (thermal barrier coating) is applied by means of a EB-PVD process. The crucible is adapted to contain the ceramics separately from one another. The scan frequency of the electron beam is adapted in relation to the difference in vapour pressure between both materials and to the attainable composition.

FIG.1



Description

[0001] The present invention relates generally to thermal barrier coatings (TBCs) and relates more particularly to articles having a ceramic TBC and to apparatus and methods for making such articles.

[0002] Electron beam physical vapor deposition (EB-PVD) is one method for coating substrates or other components with thin layers of columnar grain coatings, and is typically performed within a sealed chamber that is maintained at a low gas pressure. The application of ceramic TBCs to substrates fabricated from superalloys is known, for example from U.S. Pat. Nos. 4,321,311 to Strangman, which discloses columnar grain ceramic thermal barrier coatings; 4,405,659 to Strangman, which discloses a method for producing columnar grain ceramic TBCs; 4,405,660 to Ulion et al, which discloses a method for producing metallic articles having durable ceramic TBCs; and 5,087,477 to Giggins, Jr. et al., which discloses an EB-PVD method for applying ceramic coatings.

[0003] During EB-PVD, an electron beam impinges upon a coating target provided in solid form, e.g., as a stick or rod of material. The target is held in a cooled crucible, generally in the shape of a hollow cylinder. The beam heats the exposed end of the target, thereby forming a molten pool of target material. The material vaporizes, and the vapor or evaporant fills the chamber and condenses upon the surface of the substrate to form the coating. One such target/coating material is yttria stabilized zirconia (YSZ), which is characterized by constituents having similar vapor pressures. Accordingly, the constituents tend to vaporize at similar rates, and the composition of the resultant TBC corresponds to the composition of the target.

[0004] The general purpose of TBCs is, of course, to reduce heat flow into the component, thereby protecting the substrate. In aircraft applications, and particularly with respect to the first several turbine stages, turbine blades and vanes are subjected to gas temperatures of up to 2500-3000° F (1371-1649°C), which are well above the melting point of the underlying substrate. The TBC therefore must have a low thermal conductivity and usually the component must also be cooled. However, providing cooling air to the component reduces the operating efficiency of the turbine.

[0005] One known target/coating material is yttria stabilized zirconia (YSZ), which is characterized by constituents having similar vapor pressures. Accordingly, the constituents tend to vaporize at similar rates when heated, and the composition of the resultant coating corresponds to the composition of the target. 7YSZ, YSZ including about 7 w/o yttria, applied by EB-PVD has a relatively constant thermal conductivity of about 15-20 Btu-in./(hr-ft^2-°F) or about 2 - 2.5 W/(m-°C), between about room temperature and about 2200° F(204°C). Its thermal conductivity tends to increase with increasing temperature. While YSZ has served as a satisfactory TBC for a number or years, lower thermal conductivity TBCs are desired.

[0006] A TBC having lower thermal conductivity offers several advantages for aircraft and other gas turbine applications. Given a constant TBC thickness and gas temperature, blade/vane temperatures are lowered thereby extending blade/vane life. Given a constant coating thickness and metal temperature, higher gas temperatures are possible thereby improving efficiency. Given a constant gas temperature and constant metal temperature, thinner coatings may be utilized, which greatly reduces the pull exerted by a rotating blade and enables use of smaller, lighter disks and/or increased creep life. Moreover, thinner coatings are expected to be more durable than thicker coatings, to the extent that thermal stresses in the thicker coatings are believed to contribute to TBC failure. Variations of the above, e.g., application of a somewhat thinner TBC and operation at a somewhat higher gas temperature, may also be desirable.

[0007] In an effort to generate TBCs having improved characteristics such as reduced thermal conductivity, other combinations of constituents have been utilized. U.S. Pat. No. 5,334,462 to Vine et al. discloses a ceramic insulating material and insulating coating made thereof. The coating material is a yttria strengthened ceria. The addition of a small amount of yttria, e.g., 0.5 w/o (0.5 percent by weight) significantly hardens the ceria and provides a material which is useful as a TBC. It was suggested that the above-noted beneficial effects of yttria strengthened ceria apply up to, or even above, the solid solubility limit of yttria in ceria, which is about 12 w/o yttria.

[0008] Test applications of this material applied by EB-PVD, in which a unitary, solid source of yttria and ceria target material is employed, indicate that EB-PVD does not provide TBCs with a percentage of yttria comparable to the target. It is believed that since the ceria has a significantly higher vapor pressure than yttria, the resulting TBC necessarily has a significantly lower weight percentage of yttria than does the target. As noted in Vine et al., a target having 9 w/o yttria results in a TBC having only 0.5 w/o yttria using the above-described EB-PVD techniques. Moreover, solid single source targets of constituents which are not miscible, tend to crack during heating due to the thermal gradients that are generated between the two distinct constituents.

[0009] In addition, it is preferable that TBCs also exhibit erosion resistance.

[0010] It is a general object of the present invention to generate an article having an improved ceramic TBC.

[0011] It is also a general object of the present invention to provide an apparatus, and a method, for producing mixtures of two or more evaporants to form TBCs.

[0012] It is a more specific object of the invention in its preferred embodiments at least to provide a TBC having a lower thermal conductivity than known TBCs.